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Abstract: Abstract Objectives: To compare the alterations in esthetic appearance and slot morphology/integrity of two main types of esthetic brackets caused after clinical use. Materials and Methods: Sixteen ceramic (CR) and 16 plastic (PR) central incisor brackets were obtained from 16 young adult patients at the end of treatment in a prospective randomized manner. As controls, 12 ceramic (CC) and 12 plastic (PC) nonused brackets were also examined. Three representative slot width measurements were obtained through micrometric microscopy. Visual inspection of optical microscopy images, surface electron microscopy (SEM), and energy-dispersive x-ray spectroscopy (EDS) were also performed. Results: Intraoral exposure time varied from 5 to 20 months (mean, 12.4; $P = .73$). Two-way analysis of variance revealed significant differences in slot width among the different materials and a significant interaction between the material effect and its status ($P < .001$). Bonferroni post hoc tests on material × status effect showed significant differences between CC (95% confidence interval [CI]: 434.5, 447.0) vs PC (95% CI: 460.2, 472.8), CC vs CR (95% CI: 453.2, 464.4), and PC vs PR (95% CI: 448.8, 458.9). Interestingly, a significant difference was not detected for CR vs PR. Slot width was correlated with the time under clinical use only for plastic brackets (PR: $r = -.64$, $P < .01$). Visual inspection of the optical microscopy images did not reveal any major macroscopic morphological disfigurements or significant discolorations. However, a rough and irregular slot wall surface was evident after clinical use (also with SEM), especially in the bottom of the slot. Conclusions: Both bracket types presented adequate clinical performance at least for the time period studied and in terms of esthetic appearance and morphologic integrity.

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Original Article

Comparative assessment of clinical performance of esthetic bracket materials

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ABSTRACT

Objectives: To compare the alterations in esthetic appearance and slot morphology/integrity of two main types of esthetic brackets caused after clinical use.

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Conclusions: Both bracket types presented adequate clinical performance at least for the time period studied and in terms of esthetic appearance and morphologic integrity. (*Angle Orthod.* 0000;00:000–000.)

KEY WORDS: Orthodontic brackets; Ceramic; Plastic/polycarbonate; Clinical performance

INTRODUCTION

In recent years, the increased esthetic demands of patients who seek orthodontic treatment[1] have led to the development of various esthetic materials, including orthodontic brackets. The two primary types of esthetic brackets are the ceramic and the plastic brackets.[2]

The plastic brackets have become quite popular since the 1990s, when the damage to enamel that was caused by the ceramic brackets during debonding became evident.[3] Despite the safer removal, several disadvantages of the plastic brackets were observed during clinical usage, disputing their effectiveness. These can be summarized in color changes, morphological disturbances, and structural or hardness derangements.[4,5] Some of these problems also concern ceramic brackets.[2,6] As a result, the clinical efficiency of these materials may sometimes be

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considerably reduced during treatment due to intraoral aging.

For instance, the straightwire technique is primarily based on the concept that by placing the wire in the bracket slot, certain forces and moments will be fully transferred to the tooth in a standard manner, and thus, the desirable tooth movement will occur. However, several factors can disrupt this constant wire/slot relationship and thus not always lead to the expected result. These factors are related to wire, bracket, and ligation characteristics that may vary in several cases due to different raw material properties or to intraoral aging.[7]

Although the esthetic brackets are widely used in everyday practice, their clinical effectiveness has not yet been adequately investigated. Most of the existing evidence in the field comes from laboratory tests[6,8] and setups that attempt to simulate intraoral conditions.[9,10] For example, artificial aging of plastic brackets has a plasticizing effect on the bracket, attributed to water absorption, which is considered to reduce its torque capacity.[11] However, because of the distinctive characteristics of the oral cavity, a successful simulation of the clinical conditions is usually not possible.[12]

The main factors that distinguish the oral environment are the presence of complex oral flora and their byproducts, temperature variability and moisture. These parameters in combination with the simultaneous presence of stress, may evidently affect some of the biomaterials' properties. Since this environment cannot be simulated under current in vitro research methodological approaches, retrieval analysis through clinical designs can prove to be a really valuable tool for the evaluation of function and effectiveness of intraoral appliances, such as esthetic orthodontic brackets.[12]

Thus, the aim of the present study is to evaluate the surface morphology and composition of ceramic and plastic brackets and to examine possible alterations in their esthetic appearance and slot morphology/integrity that might be evident after clinical usage. Potential associations of the observed changes with the time under clinical use are also investigated.

MATERIALS AND METHODS

The material of the study consisted of 16 ceramic (CR; GAC, Mystique) and 16 plastic (PR; American Orthodontics, Silkon) central incisor brackets of 0.018 in. (457.2 μm) slot. These were obtained from 16 young adult patients (eight for each group) at the end of their treatment. The power of the study for all pairwise comparisons was calculated above 0.8 for a difference of 2.5% (approximately 12 μm) in slot width dimensions and at α level .05. All patients were treated by the same experienced clinician and were randomly allocated to one of the bracket types before treatment.

When a patient was planned for esthetic bracket placement, the patient was allocated to one group. The consecutive patient was allocated to the other group, and so on. Only young adult patients (18–30 years) treated with full fixed appliances and not any kind of restoration in the maxillary incisors were included in the study. No other inclusion criteria were applied. All patients had good/excellent oral hygiene at the start or during treatment. This was controlled regularly during the appointments as in everyday practice, and no special measures/criteria were applied. Two cases (one for plastic and one for ceramic brackets) in which central incisor brackets accidentally debonded during treatment were excluded from the study. In all cases, ligation was performed with elastomeric ligatures, except from the final stage of treatment in which stainless-steel ligatures were used. In all patients, the final wire was 0.016 × 0.022 inch stainless steel and stayed in place for at least 1 month. As controls, 12 ceramic (CC) and 12 plastic (PC) brackets of same types were also examined.

All retrieved brackets and selected control brackets were photographed with a photographic microscope (Elvar, Leitz, Wetzlar, Germany) under standard conditions with 1.25, 3.5, and 5 magnification factor for visual inspection.

To evaluate the alterations in slot morphology/integrity of the two types of esthetic brackets caused after clinical use, three representative measurements (distal edge, middle, mesial edge) were obtained for each slot (56 brackets × 3 = 168 measurements) through a micrometric microscope. For this purpose, two wax matrices (one for plastic and one for ceramic brackets) were constructed by placing a 0.018 × 0.025 inch stainless-steel wire into the bracket slot and adjusting the wire-slot system to obtain a vertical position of the slot relative to the measurement plane. All brackets were placed in these wax matrices, tested for proper position with placement of the wire in the slot, and then measured after careful removal of the wire. Group comparisons as well as correlations between intraoral exposure time and slot dimensions of retrieved brackets were performed.

The surface morphology was investigated through surface electron microscopy (SEM; Quanta 200, FEI, Eindhoven, the Netherlands) in selected control and retrieved samples. The SEM was operated at 30 kV accelerating voltage, 109 mA beam current, and low vacuum chamber pressure where imaging of nonconductive specimens can be done without the need for conductive coating. The nominal magnification was 25×. Secondary electron images and back-scattered electron images were collected by a large field detector.

Table 1. Description of the Sample Used for the Study and Comparative Statistics[a]

	Sex	Age, Mean ± SD, y	Intraoral Exposure, Mean ± SD, mo
CR group (n = 8)	3M & 5F	23 ± 4.3	12.8 ± 3.3
PR group (n = 8)	2M & 6F	25 ± 3.6	12.0 ± 6.3
Total	5M & 11F	24.5	12.4 ± 4.9
P value	.41[b]	.33[c]	.74[c]

[a] CR indicates ceramic retrieved; PR, plastic retrieved.
[b] Chi-square.
[c] Unpaired *t*-test.

Furthermore, energy-dispersive x-ray spectroscopy (EDS) was used for the elemental analysis or chemical characterization of selective control samples. The nominal magnification was 200×, the collecting window 640 × 640 μm, 300 seconds acquisition time, 25% to 40% dead time, and 300 seconds data selection time.

Statistical Analysis

After testing for normality of data through the Shapiro-Wilk test and homogeneity of variances through the Levene test, parametric statistics were performed for the analysis of the results ($\alpha = .05$).

Between-group differences in age and intraoral exposure time were tested with unpaired *t*-tests, while sex distribution similarity was tested with the chi-square test.

Regarding measurements of slot width, two-way two-factor analysis of variance (ANOVA) was used for testing differences among groups (CC, CR, PC, and PR), while Bonferroni post hoc tests were performed to further investigate between-group differences. The two factors under study were the material (ceramic or plastic) and the status (control or retrieved) of brackets.

Spearman's correlation coefficient was used to test for potential correlations between slot width of retrieved samples and intraoral exposure time. This is a nonparametric test, but it can also detect nonlinear correlations, and thus it was preferred instead of Pearson's correlation.

Method Error

For identification of the micrometric microscope error, 36 measurements in six bracket pairs (3 × 2 ceramic and 3 × 2 plastic) obtained from six patients were repeated by the same investigator 1 week after the first measurement. Systematic error was evaluated with paired *t*-tests between corresponding measurements, while random error was calculated using Dahlberg's formula. No systematic error of measurements was detected ($P = .39$). The average random error was 1.70, which is considered acceptable.

RESULTS

A detailed description of the study sample is provided in Table 1. The intraoral exposure time varied from 5 to 20 months (mean, 12.4 months) and did not differ significantly between groups ($P = .73$). The two groups were also similar in terms of age and sex distribution of the patients.

Visual inspection of the optical microscopy images of the brackets did not reveal any major macroscopic morphological disfigurements. Discoloration was usually localized at the bottom of the slot in both bracket types, while discoloration in other parts of the brackets was limited in few cases (Figure 1). Discolorations that were considered visible during clinical use were less than 8% for both bracket types. In 15% of the plastic and 20% of the ceramic brackets, there was discoloration in the gingival side at the bracket wing slot to base connection, but this is not considered visible at use since this location is occupied by the ligation. Both discoloration patterns described were not directly related to the time of clinical use, indicating that other influential factors may be more important.

Two-way ANOVA identified significant differences in slot width among the different materials ($P < .001$) and a significant interaction between the effect of the material and its status ($P < .001$). Bonferroni post hoc tests on material × status effect showed significant differences between CC (95% confidence interval [CI]: 434.5, 447.0) vs PC (95% CI: 460.2, 472.8), CC vs CR (95% CI: 453.2, 464.4), and PC vs PR (95% CI: 448.8, 458.9). Interestingly, a significant difference was not detected for CR vs PR (Table 2).

Spearman's rho identified a significant correlation between the slot dimensions observed in the retrieved plastic brackets and the time under clinical use (PR: $r = -.64$, $P = .007$). No such correlation was evident for ceramic brackets (CR: $r = -.10$, $P = .738$). Further analysis showed that this correlation was evident for the two edges of the plastic brackets but not for the middle of the slot (Table 3).

SEM showed the presence of an irregular surface of both ceramic and plastic brackets even before treatment. The slot wall surface, especially at the bottom of the slot and in plastic brackets, became

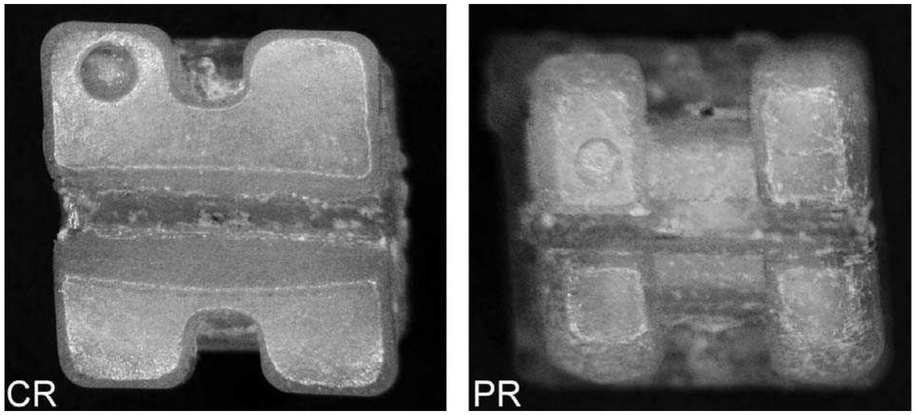

Figure 1. Optical microscopy images of ceramic retrieved (CR, left) and plastic retrieved (PR, right) brackets after 17 months of clinical use. Note the discoloration (shown as black) at the bottom of the slot in both brackets and at the gingival side of the wing slot to base connection in the PR bracket.

more irregular even after 7 months of clinical use (Figure 2).

EDS analysis showed that the ceramic bracket is primarily composed of oxygen (O), aluminum (Al), and carbon (C) in decreasing order, while there are also traces of silicon (Si). On the other hand, the plastic bracket includes more elements as it is composed primarily of carbon, and oxygen, while there are also small amounts of silicon, calcium (Ca), aluminum, and sodium (Na; Figure 3; Table 4).

DISCUSSION

Retrieval analyses have gained special interest in biomaterials research since the in vivo environment cannot be adequately simulated under current in vitro research methodological approaches.[12] This is fundamental for determining the actual performance of a material as opposed to the projected service profile derived from laboratory studies.

In general, the decision regarding the specific type of esthetic bracket that should be used in a treatment is based on manufacturer information, laboratory findings, clinical experience, cost criteria, or other assumptions that are not evidence based. The present study attempted to investigate the extent of certain aspects of intraoral aging of plastic and ceramic orthodontic brackets and to explore possible consequences on the clinical effectiveness of these materials in everyday practice.

EDS analysis showed that ceramic brackets are composed mainly of Al and O, and thus it is logical to assume that ceramic brackets are made of alumina oxide with traces of Si or Si oxide. C should be attributed to surface contamination rather than an elemental component. On the contrary, C is the predominant element of plastic brackets, as is expected, followed by O and small amounts of Si, Ca, Al, and Na. The chemical characterization of the brackets clarifies their composition, which may influence the mechanical properties and performance of the materials, and thus helps to the interpretation of the findings.

Ceramic brackets are supposed to be quite stable macroscopically, but irregularities in the inner slot surface increase pressure expressed by the wire to the protruded points and thus lead to attrition during clinical use. The brittleness of the material does not allow significant deformation before fracture, and thus breakage occurs with relatively little energy.[13] In the present study, no significant correlation between the intraoral exposure time and the slot width was detected for retrieved ceramic brackets, thus indicating a more stable condition during clinical use and that changes occur at a certain time period and remain stable afterward.

Table 2. Descriptive and Comparative Statistics Showing Between-Group Differences in Slot Width[a]

	Ceramic, μm		Plastic, μm		
	Mean	SD	Mean	SD	*P* Value
Control	440.7	12.9	466.5	16.4	<.05
Retrieved	458.7	23.4	454.3	20.2	NS
P value	<.05		<.05		

[a] NS indicates not significant.

Table 3. Spearman's rho Correlation Between the Time of Clinical Use and the Change in Slot Width[a]

	Distal Edge		Middle		Mesial Edge	
	r	*P*	*r*	*P*	*r*	*P*
CR	−.12	.66	.02	.94	−.12	.68
PR	−.81*	.00	.11	.67	−.64*	.01

[a] CR indicates ceramic retrieved; PR, plastic retrieved.
* $P < .05$.

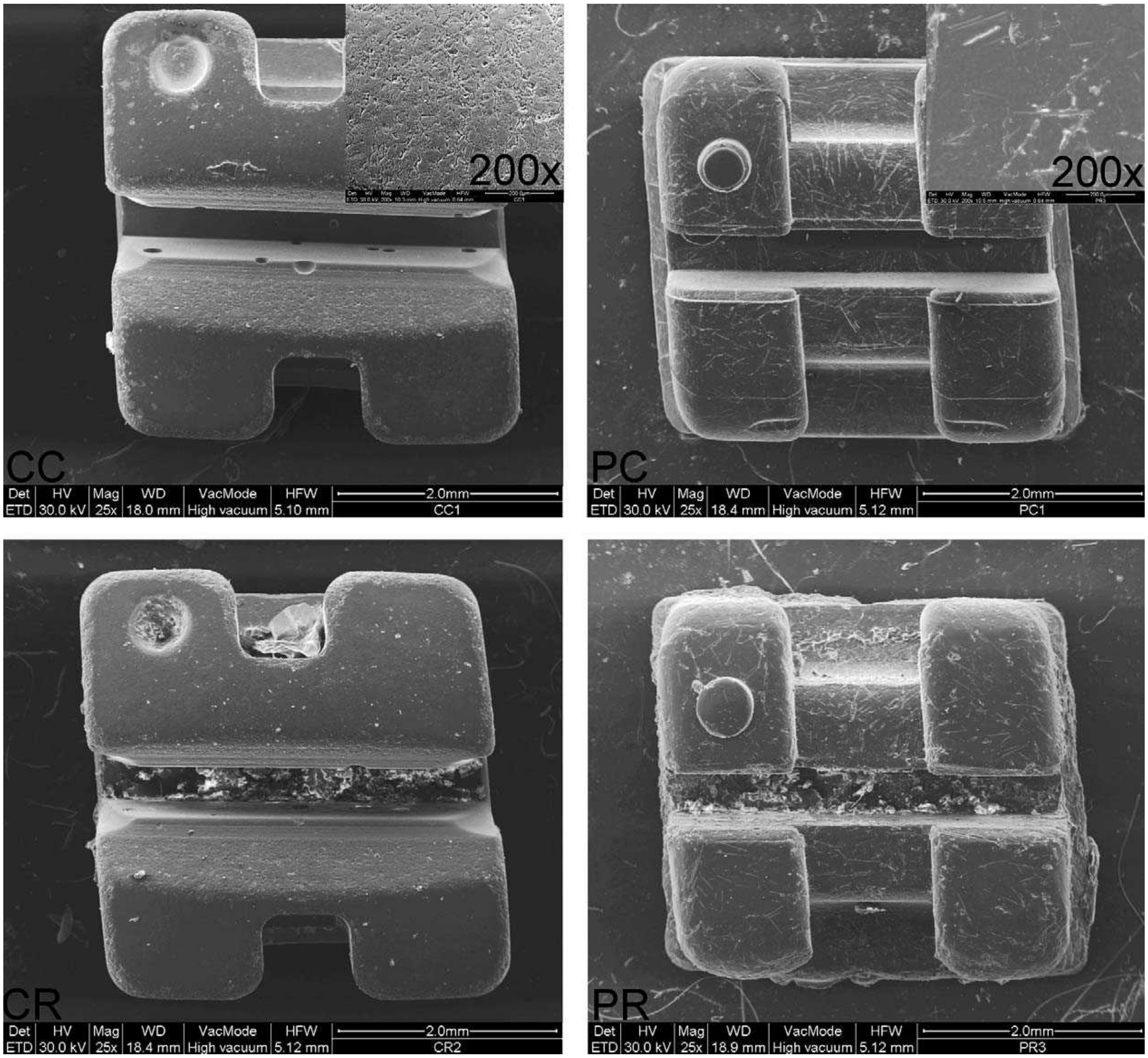

Figure 2. Secondary electron images (SEi), obtained through surface electron microscopy, of ceramic control (CC, upper left), plastic control (PC, upper right), ceramic retrieved (CR, lower left), and plastic retrieved (PR, lower right) brackets. The CR and PR brackets shown were retrieved after 7 months of clinical use.

The decrease in slot dimensions observed in the retrieved plastic brackets can be attributed to the fact that plastic material may be subjected to plastic deformation during clinical use and debonding. The first hypothesis is strengthened by the fact that significant correlations with time were evident only for the two edges of the plastic brackets and not for the middle of the slot. This can be an effect of archwire ligation since most stresses are applied at the four corners of the bracket. Thus, it is possible to cause a plastic deformation of such pattern to it. The other possibility could be that the squeezing effect produced during bracket removal and attributed to the low Young's modulus of polycarbonate (2.0–2.4 GPa) might also contribute to this finding.[13] This factor was eliminated by removing brackets with a cutter placed in the bracket to tooth interface that was occupied by the adhesive resin.

Polycarbonate can undergo large plastic deformations without cracking or breaking. The absorbed water through disruption of secondary bonding between polymeric chain segments has a plasticizing effect.[14] This was assumed to have a negative effect in the torque capacity of polycarbonate brackets and led various laboratory studies to suggest that plastic brackets without a metal slot are inappropriate to deliver the desirable amount of torque in clinical conditions.[15–17] The problem was considered even greater for plastic brackets filled with ceramic particles,[17] as those examined in our case. However, such an effect was not evident in our study. The inconsistency noted between the results of the present in vivo

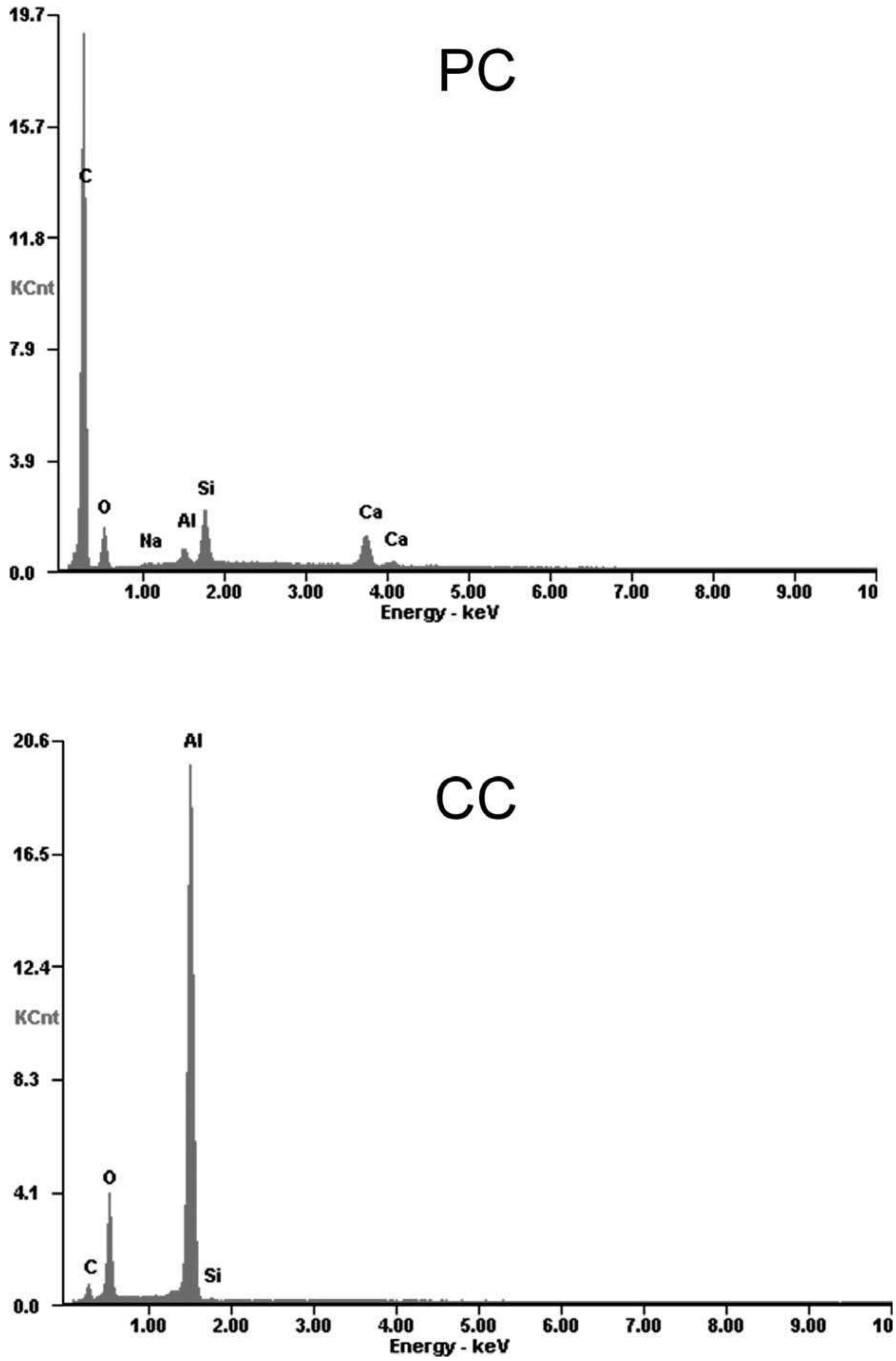

Figure 3. Energy-dispersive x-ray spectroscopy spectrums for element identification in ceramic control (CC) and plastic control (PC) brackets.

and previous in vitro studies can be attributed to the unsuccessful simulation of clinical conditions.

SEM showed the presence of a rough and irregular slot wall surface in both bracket types. The surface of the ceramic bracket was irregular even before treatment. This might jeopardize full wire engagement and disturb the desired intact relationship between the wire and the bracket slot in straightwire mechanics. However, the pattern of attrition of ceramic brackets during clinical use, along with the phenomena for the plastic brackets, which were discussed above, led to similar slot dimensions at the end of treatment. In particular, after-use slot dimensions were very close to the subscribed slot dimensions by the manufactures (0.01797 inch), suggesting adequate clinical performance for both bracket types.

Discoloration patterns were also similar for both bracket types and were not associated with time of intraoral use. Furthermore, the increased incidence of discoloration observed in the gingival side at the bracket

Table 4. Result of Energy-Dispersive X-Ray Spectroscopy Analysis Showing the Percentage by Weight (Wt%) of Each of the Elements Identified in Ceramic Control and Plastic Control Brackets

	Ceramic Brackets		Plastic Brackets	
	Element	Wt%	Element	Wt%
EDS analysis	O	46.95	C	70.06
	Al	42.47	O	24.90
	C	10.28	Si	2.39
	Si	0.30	Ca	1.73
			Al	0.71
			Na	0.20

wing slot to base connection indicated that other factors, such as plaque accumulation, may be more important for retaining the pleasing esthetic appearance of the brackets than the time of clinical use. Although this region is not considered visible at use, since it is occupied by the ligation, it is a region for which patients usually have difficulty achieving excellent hygiene. A recent in vivo study identified a significant correlation between the prevalence of *Streptococcus mutans* and *Streptococcus sobrinus* in bracket materials and the oral hygiene indices.[18] Furthermore, in the same study, the prevalence of the specific bacteria was increased in the esthetic brackets compared with metal brackets, while no difference was detected between plastic and ceramic brackets. These findings combined with our findings emphasize the need for increased oral hygiene measures in patients with esthetic brackets, both for oral health and esthetics.

CONCLUSIONS

- While the slots of plastic brackets are significantly larger than those of ceramic brackets before use, treatment parameters seem to affect both bracket types in such an opposing way that leads to similar slot width after clinical use.
- Slot width alterations were influenced by treatment time only for plastic brackets, and this may suggest more sensitivity to aging phenomena.
- In terms of esthetic appearance and morphologic integrity, both bracket types presented adequate clinical performance at least for the time period studied (5–20 months).

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